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MAXIMUM MEAN LIFT COEFFICIENT CHARACTERISTICS AT LOW TIP MACH NUMBERS OF A HOVERING HELICOPTER ROTOR HAVING AN NACA 64_1A012 AIRFOIL SECTION

By Robert D. Powell, Jr.

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SUMMARY

An investigation has been conducted on the Langley helicopter test tower to determine experimentally the maximum mean lift-coefficient characteristics at low tip Mach number and a limited amount of drag-divergence data at high tip Mach number of a helicopter rotor having an NACA 64_1A012 airfoil section and 8° of linear washout. Data are presented for blade tip Mach numbers M_t of 0.29 to 0.74 with corresponding values of tip Reynolds number of 2.59×10^6 and 6.58×10^6. Comparisons are made between the data from the present rotor with results previously obtained from two other rotors: one having NACA 0012 airfoil sections and the other having an NACA 0009 airfoil tip section. At low tip Mach numbers, the maximum mean lift coefficient for the blade having the NACA 64_1A012 section was about 0.08 less than that obtained with the blade having the NACA 0009 tip section and 0.21 less than the value obtained with the blade having the NACA 0012 tip section. Blade maximum mean lift coefficient values were not obtained for Mach number values greater than 0.47 because of a blade failure encountered during the tests.

The effective mean lift-curve slope required for predicting rotor thrust varied from 5.8 for the tip Mach number range of 0.29 to 0.55 to a value of 6.65 for a tip Mach number of 0.71. The blade pitching-moment coefficients were small and relatively unaffected by changes in thrust coefficient and Mach number. In the instances in which stall was reached, the break in the blade pitching-moment curve was in a stable direction. The efficiency of the rotor decreased with an increase in tip speed. Expressed as figure of merit, at a tip Mach number of 0.29 the maximum value was about 0.74. Similar measurements made on another rotor having an NACA 0012 airfoil and with a rotor having an NACA 0009 tip section, showed a value of 0.75. Synthesized section lift and profile-drag characteristics for the rotor-blade airfoil section are presented as an aid in predicting the high-tip-speed performance of rotors having similar airfoils.

INTRODUCTION

A general research program has been in progress at the Langley Research Center (refs. 1 to 6) to determine the low-tip-speed stall and high-tip-speed compressibility effects on rotors having various NACA airfoil tip sections as the primary variable. The present investigation is a continuation of this program, in which emphasis is placed on the low-speed, maximum mean lift coefficient characteristics of a helicopter rotor having an NACA 64_1A012 airfoil section, a constant chord, and 8° of linear washout. The low-speed, maximum lift characteristics of this helicopter rotor will be useful in rotor design studies, particularly in the analysis of the stall characteristics of the retreating blade in forward flight.

The hovering performance of the rotor over a tip Mach number range of 0.29 to 0.74 (disk loading up to 4.83 lb/sq ft) is presented. Performance data obtained at Mach numbers above 0.47 are incomplete because of blade structural failure during part of the tests at a tip Mach number of 0.74. The blade low-speed maximum mean-lift and drag-rise characteristics are discussed and a comparison of the performance of the present rotor with that of other rotors (NACA 0009 and NACA 0012 sections) is presented. The experimental Mach numbers for drag divergence are also compared with those shown by two-dimensional data.

Profile-drag-coefficient and lift-coefficient curves as a function of airfoil-section angle of attack and Mach number, which were synthesized from the rotor experimental results by use of two-dimensional data on the NACA 64_1-012 airfoil (ref. 7) as an initial guide, are also presented.

SYMBOLS

a straight-line slope of section lift coefficient with section angle of attack (assumed to be 5.73 in calculations for incompressible flow curve), per radian, c_l/α_r

$\bar{a}$ effective mean lift-curve slope, $5.73 \dfrac{C_{T,measured}}{C_{T,calculated}}$

b number of blades

c blade chord, ft

$c_{d,o}$ airfoil-section profile-drag coefficient

c_l	airfoil-section lift coefficient
$\bar{c}_l$	rotor-blade mean lift coefficient, $6C_T/\sigma$
C_m	rotor-blade pitching-moment coefficient, $\dfrac{M_Y}{\frac{R\rho}{2}(\Omega R)^2 c^2}$
C_Q	rotor torque coefficient, $\dfrac{Q}{\pi R^2 \rho (\Omega R)^2 R}$
$C_{Q,o}$	rotor profile-drag torque coefficient, $\dfrac{Q_o}{\pi R^2 \rho (\Omega R)^2 R}$
C_T	rotor thrust coefficient, $\dfrac{T}{\pi R^2 \rho (\Omega R)^2}$
M	Mach number
M_t	rotor blade tip Mach number
M_Y	rotor-blade pitching moment about 0.25 chord, lb-ft
N_{Re}	Reynolds number at blade tip, $\dfrac{\rho \Omega R c}{\mu}$
Q	rotor torque, lb-ft
Q_o	rotor profile-drag torque, lb-ft
R	rotor-blade radius, ft
T	rotor thrust, lb
α	airfoil-section angle of attack, deg
α_r	blade-section angle of attack, deg or radians
$\theta_{.75}$	blade-section pitch angle at 0.75R measured from line of zero lift, radians
θ_1	difference between hub and tip pitch angles: positive when tip angle is larger, deg
μ	coefficient of viscosity, slugs/ft-sec

ρ mass density of air, slugs/cu ft

σ rotor solidity, $bc/\pi R$

Ω rotor angular velocity, radians/sec

Figure of merit is equal to $0.707 C_T^{3/2}/C_Q$

APPARATUS

The rotor used for this investigation was a fully articulated, two-blade rotor with the flapping hinge located on the center of rotation and the drag hinge 12 inches outboard of the center. The distance from the ground to the rotor hub is 42 feet.

A sketch of a rotor blade with pertinent dimensions is shown in figure 1. The rotor blades used in the investigation were constructed of Fiberglas and incorporated a steel spar in the leading edge. The center of gravity of the rotor blades was located at the 25 percent chord.

The radius of the blades from the center of rotation was 17.24 feet and the rotor solidity was 0.046. The blades had a constant chord of 1.25 feet. The rotor blades were smooth and fair over the entire chord with finished contour tolerances, back to about 30 percent chord, of +0.000 to -0.005 inch. The rotor blades had 8.0° of linear washout (about 0.47° of twist per foot).

TEST METHODS AND ACCURACY

The tests were run by setting given rotor-blade collective pitch angles and varying the rotor speed through a range of tip Mach numbers until either the blade limiting stress was reached or until a further increase in blade pitch did not increase the rotor thrust. The maximum disk loading obtained was 4.83 pounds per square foot. The blade tip Mach numbers varied from 0.29 to 0.74 with corresponding Reynolds numbers of 2.59×10^6 to 6.58×10^6, respectively. At each pitch setting, data were recorded from visual dial readings and by an oscillograph. Quantities measured were rotor thrust, rotor torque, blade pitch angle, blade drag angle, blade flapping angle, blade pitching moment, and rotor-shaft rotational speed. The range of test conditions was chosen to determine the low-tip-speed rotor-blade maximum mean lift coefficient and the high-tip-speed compressibility drag rise.

The estimated accuracies of the basic quantities measured during the test are as follows:

Rotor thrust, lb	±20
Rotor torque, lb-ft	±50
Rotor rotational speed, rpm	±1
All angular measurements, deg	±0.2

The overall accuracy of the plotted results is believed to be within ±3 percent. For example, at a rotor-blade mean lift coefficient $\bar{c}_l$ of 0.46 $(C_T = 0.00348)$ and an $M_t = 0.47$, the accuracy of the plotted data based on repeatability was about 3 percent for the thrust value of 2,700 pounds, 3 percent for the torque value of 2,196 pound-feet, and 0.2 percent for a rotational speed of 288 revolutions per minute. All data have been corrected to zero wind speed by the method of reference 8.

RESULTS AND DISCUSSION

The measured hovering performance and rotor-blade pitching-moment curves are presented. A detailed analysis of the effects of stall and compressibility shown by these data is presented for tip Mach numbers ranging from 0.29 to 0.47. Data obtained for M_t of 0.51 to 0.74 are incomplete for the high angles of attack due to blade failure at $M_t = 0.74$. Synthesized airfoil-section data deduced from the measured rotor performance are also shown.

Rotor Hovering Performance

The effect of Mach number on rotor performance is shown in figure 2 as the variation of thrust coefficient with torque coefficient for blade tip Mach numbers from 0.29 to 0.74. An incompressible-flow rotor-performance curve calculated by using conventional strip analyses (ref. 9) and incompressible drag coefficients is plotted for comparison with the experimental data. The calculated rotor-performance curve is based on the linear lift-coefficient slope $(c_l = a\alpha_r$, where $a = 5.73)$ and the commonly used drag polar $(c_{d,o} = 0.0087 - 0.0216\alpha_r + 0.400\alpha_r^2)$ of reference 10. Since reference 9 does not allow for any tip loss, a 3-percent tip-loss factor (the outer 3 percent of the blade is considered to produce no lift but to have profile drag) was used in the calculations.

In the low range of C_T (0 to 0.0025) the experimental data showed less power required at all tip Mach numbers than that indicated by the incompressible (no stall) flow curve. This result indicates that the rotor actually has less profile drag than that predicted by the assumed profile-drag polar. Above a value of C_T of 0.0025 the experimental data are in fair agreement at tip Mach numbers of 0.29 to 0.60 up to a C_T value of 0.0040 $\left(\bar{c}_l = 0.52\right)$. Past this value of C_T, the experimental data (limited to $M_t = 0.29$ to 0.47) show a large increase in torque coefficient as the blade approaches maximum lift. Increasing tip speed caused the experimental rotor performance to deteriorate progressively. The point at which the experimental data separated from the calculated curve indicates the critical value at which stall and compressibility losses begin.

Rotor mean lift coefficients.- The maximum value of $\bar{c}_l$ obtained with the present rotor was 0.92 which is somewhat less than that obtained with other rotors having similarly smooth and fair surfaces but different airfoil sections. For example, the maximum value of $\bar{c}_l$ given in reference 6 for the rotor having NACA 0012 sections and a constant chord was 1.13. A somewhat higher maximum $\bar{c}_l$ might be expected from the rotor with NACA 0012 sections than from the rotor having NACA 64_1A012 sections because of a more favorable section leading-edge radius.

The maximum $\bar{c}_l$ for the rotor having an NACA 0009 tip section was 0.995 (ref. 4). However, this rotor had an 18-percent-thick root section. It is probable that the thicker inboard sections of this rotor were an important factor in its having a slightly higher maximum $\bar{c}_l$ than was obtained from the rotor having an NACA 64_1A012 section. At $\bar{c}_l$ of 0.85 $\left(C_T = 0.0065\right)$, the increase in power from $M_t = 0.29$ to $M_t = 0.47$ for the test blades with the NACA 64_1A012 section was about 35 percent compared with values of 21 and 12 percent (obtained at the same operating condition) for the blades with the NACA 0009 tip-section blades and NACA 0012 section, respectively.

Data recorded at tip Mach numbers above 0.47 were incomplete inasmuch as the data were obtained only up to thrust coefficients just prior to or at the point where drag divergence might be expected. Maximum values of C_T that were obtained are indicated in figure 2 by leaders with identifying Mach number values.

Rotor efficiency.- The efficiency of the rotor at various tip Mach numbers up to 0.47, expressed in terms of figure of merit, is shown in figure 3. The maximum figure of merit obtained at tip Mach numbers of 0.29 and 0.38 was about 0.74 compared with a value of 0.75 obtained with blades having NACA 0009 airfoil tip sections (ref. 4) and blades having NACA 0012 airfoil sections (ref. 6). As the tip Mach number increases, the maximum value of the figure of merit decreases.

Effect of tip Mach number on blade lift.- Figure 4 shows the variation in rotor thrust coefficient as a function of the blade pitch angle at the 0.75 radius over a range of tip Mach numbers from 0.29 to 0.74. In general the thrust coefficient was little affected by M_t up to a value of $M_t = 0.51$ except for $M_t = 0.47$ where data indicate higher values of C_T over the intermediate range of blade-section pitch angles. As would be expected, a substantial increase in rotor thrust coefficient for a given blade-pitch angle was obtained as the tip Mach number was increased past 0.60.

Values of effective mean lift-curve slope $\bar{a}$ were deduced from figure 4 for the various tip Mach numbers and are plotted in figure 5 as a function of blade tip Mach number. These values of $\bar{a}$ were obtained by taking the value of C_T obtained from measured data at a particular pitch angle and Mach number, dividing it by the value of C_T obtained from two-dimensional incompressible-flow calculations at the same pitch angle, and multiplying this ratio of thrust coefficients (measured over calculated) times the value 5.73. An average curve is shown for blade-pitch angles of 6°, 8°, and 12° at the 0.75 radius. The figure shows that the mean lift-curve slope had an average value of 5.8 at tip Mach numbers ranging from 0.29 to 0.55. As tip Mach number is increased, higher lift-curve-slope values are obtained. For example, at $M_t = 0.74$ and $\theta_{.75} = 6^{\circ}$, a value of $a \approx 6.6$ will be required to predict the rotor thrust when the strip analysis method outlined in reference 9 is used.

Rotor-Blade Pitching Moments

Rotor-blade pitching-moment data are necessary to determine the rotor control forces and are important in blade vibration and stability analysis. A comparison of the blade pitching-moment characteristics for representative tip Mach numbers of 0.29 to 0.74 for the rotor blade tested as a function of rotor thrust coefficient is shown in figure 6. The pitching-moment data represent the measured rotor-blade moments about the blade pitch axis (0.25 chord) and include aerodynamic and blade mass forces.

Changes in blade pitching-moment coefficient as thrust coefficient is increased are probably largely due to the displacement of the blade center of pressure from the blade center of gravity. Since the position of the blade center of pressure is not precisely known and since the actual blade pitching moments were reasonably small (from -79 to 65 lb-ft), no attempt was made to separate the mass moments from the aerodynamic moments. The most important factor is the presence or absence of abrupt changes in pitching-moment slopes rather than the actual values.

The pitching-moment coefficients that were obtained through the tip Mach number range of 0.56 to 0.74 remained slightly positive, that is, nose up, with very little variation in the moments with increases in thrust. At the lower tip Mach numbers (0.29 to 0.47) the pitching-moment coefficients were almost entirely negative and became more negative gradually as thrust coefficients were increased until the rotor approached its maximum thrust coefficient and a portion of the blade stalled. As would be expected from the stall characteristics of the NACA 64_1A012 airfoil section, a rearward shift of the center of pressure occurs on the blade at stall and tends to cause nose-down pitching moments.

Rotor Profile-Drag Torque

The principal effect of stall or compressiblity on the rotor performance has been shown to be a rapid increase in the rotor profile-drag torque. (See refs 1 to 6.) Figure 7(a) presents the rate of growth of profile-drag torque as a function of the ratio of $\left(C_{Q,o}\right)_{measured}$ to $\left(C_{Q,o}\right)_{calculated}$ plotted against the calculated rotor-blade-tip angle of attack. Values of α_r for drag divergence are represented by the point at which the curves faired through the experimental data exceed a profile-torque coefficient ratio of unity. At tip Mach numbers ranging from 0.29 to 0.47, the ratio of profile-drag torque coefficients did not exceed unity up to a calculated blade-tip angle of attack of 4°. This result indicates that there was no drag increase over that represented by the assumed drag polar. In fact, at the lower angles of attack, the blade has less profile drag than that predicted by the assumed drag polar, as indicated by the data points below the profile-drag torque-coefficient ratio of unity. At blade-tip angles of attack greater than 4°, the profile-drag torque-coefficient ratios became greater than unity, which indicates that the assumed drag polar underestimated the actual profile drag. As the angle of attack was increased past the drag divergence point at the various tip Mach numbers, the increase in the profile-drag torque coefficient was, for the most part, gradual. In the low tip Mach number range of 0.29 to 0.42 there is no orderly progression of the tip angle for profile-drag increase as a function of M_t. At a Mach number of 0.47, the principal factor influencing the point of drag rise is the tip Mach number. In this instance, the curve shows that the profile-drag torque was approximately doubled for tip angles of attack 3° beyond the initial drag-rise point.

Figure 7(b) shows the same experimental data that were shown in figure 7(a) except that the drag-divergence values in figure 7(b) for α_r at the various Mach numbers were obtained by a straight-line fairing of the data points. Considerable scatter in these plotted points exists at some Mach numbers (especially $M_t = 0.47$). In view of this scatter a linear (or straight-line) fairing of the data points as shown in figure 7(b) might be considered more appropriate. More data points than are presently available will be required before the most accurate fairing of figure 7(a) can be determined; however, the failure of the rotor blades made this impossible in the present investigation.

Figure 8 shows the rotor profile-drag-torque ratio rise as a function of rotor-blade mean lift coefficient. At the low tip Mach numbers (0.29 and 0.33), the maximum mean lift coefficient before drag rise (defined as the point at which the profile-drag-torque ratio becomes greater than unity) was about 0.58. This value of $\bar{c}_l$ is about 35 percent lower than that reported in reference 6 for a rotor having an NACA 0012 airfoil section and about 29 percent lower than that reported in reference 4 for a rotor having an NACA 0009 tip airfoil. As the tip Mach number was increased, the values of $\bar{c}_l$ for drag rise were in somewhat better agreement with values for the blades reported in references 4 and 6. For example, at a tip Mach number of 0.47 the $\bar{c}_l$ value for drag rise for the NACA 64_1A012 airfoil was 0.52 which was 18 percent and 15 percent lower than that obtained with the NACA 0012 and NACA 0009 blades, respectively. At a tip Mach number of 0.69 the values for the NACA 64_1A012 and NACA 0012 were the same ($\bar{c}_l = 0.45$), whereas the value of $\bar{c}_l$ for the NACA 0009 blade was 0.41.

Comparison of Drag-Divergence Data with Results From Two-Dimensional-Airfoil Tests

A comparison of the rotor drag-divergence Mach numbers with those predicted from two-dimensional-airfoil data is presented in figure 9. The measured drag-divergence data were obtained from figures 7(a) and 7(b). The point of drag divergence was defined as the point at which the profile-drag torque-coefficient ratio exceeds a value of unity.

The two-dimensional-airfoil drag-divergence data for the NACA 64_1-012 airfoil (ref. 7) are presented in two ways. In one case the Mach number for drag divergence was selected as the point at which $\Delta c_d/\Delta M = 0.1$. In the other case the drag-divergence Mach number was taken as the point at which the profile-drag coefficient begins to increase.

The rather abrupt decrease in the experimental Mach number for drag divergence in the tip angle-of-attack range of 4° to 5° (shown in fig. 9 by the points plotted as circles) is of interest. Although experience with the rotor of reference 4 has shown that a decrease in the experimentally defined drag-divergence Mach number occurs at moderately high angles of attack because of inboard stalling, this tendency is not found for the rotor with the NACA 64_1A012 airfoil. Calculations of the inboard blade angles of attack show the maximum values to be only 6° or 7° at tip angles of attack in the region of 4° to 5°. These values are too low for stall to occur for the test condition represented. It will be recalled that the drag-divergence Mach numbers plotted as circles in figure 9 were defined by the point at which the faired curves first exceeded the incompressible value of $\frac{(C_{Q,o})_{measured}}{(C_{Q,o})_{calculated}}$. The values for the drag-divergence Mach numbers defined by a straight-line fairing of the data points, (triangular symbol) are shown to fall approximately on the curve given in figure 9 for the two-dimensional airfoil data where drag-divergence Mach numbers were defined as the point where drag begins to increase. Experimental-data points noted by the flagged symbols are for tip Mach numbers above 0.47. Although data above this Mach number were incomplete, these values of M_t are believed to be the points that represent either the drag-divergence value or a value very close to this point. This fact was further borne out by visual data readings made during the test.

At an angle of attack of about 2° and $M_t = 0.74$ the blades show some tip relief; that is, the drag-divergence Mach number for the rotor data is greater than the drag-divergence Mach number for the two-dimensional data. At higher tip angles of attack and lower tip Mach numbers the points of drag divergence become less than the values indicated by the two-dimensional data (as much as a 0.25 difference in tip Mach number for the same angle of attack) where drag-divergence points were defined as the point of initial drag increase.

Synthesized Characteristics of the NACA 64_1A012 Airfoil Section for Rotor Performance Calculations

The section lift and drag characteristics shown in figures 10 and 11 were synthesized by the method outlined in detail in reference 6. These data, when used with an established method of performance analysis, might be used as an aid in calculating the forward-flight performance of rotors having similar airfoil sections and operating at high tip speeds. The original assumptions used for synthesizing the drag and lift curves herein are based, to a large extent, on wind-tunnel data (ref. 7) for the two-dimensional NACA 64_1-012 airfoil section. Drag and lift curves are presented for Mach numbers ranging from 0.29 to 0.74, but below or beyond these values the curves are dashed to indicate their provisional nature.

Figure 10 shows the synthesized drag coefficients for the NACA 64_1A012 airfoil section plotted as a function of Mach number for blade angles of attack from 0° to 12°. The resulting curves retain the general shape of the variation of drag with Mach number as that for the two-dimensional NACA 64_1-012 airfoil section (ref. 7) up to angles of attack of 8° or 9°. The rate of increase in section profile drag at angles of attack above 6° was somewhat greater than that indicated by the two-dimensional data.

The synthesized lift coefficients for the NACA 64_1A012 airfoil section are plotted in figure 11 as a function of Mach number for angles of attack from 0° to 12°. The section-lift-coefficient curves are almost identical to the two-dimensional lift-coefficient data for the NACA 64_1-012 airfoil section except that the maximum lift-coefficient values for $M = 0.10$, 0.20, 0.30, 0.35 were decreased to predict more accurately the actual experimental rotor performance. Above $M = 0.35$, the slopes of the two-dimensional-data curves were also decreased slightly for better correlation between the two-dimensional and experimental data.

CONCLUSIONS

The low-speed maximum mean lift coefficients $\bar{c}_l$ on a rotor having a constant-chord NACA 64_1A012 airfoil section and 8° of linear washout have been determined over a range of blade-tip Mach number M_t of 0.29 to 0.47. Maximum rotor-blade mean lift coefficients for the range of tip Mach numbers from 0.51 to 0.74 were not obtained and only a limited amount of drag-divergence data was obtained for this range. As a result of this investigation the following conclusions can be made:

1. At low tip Mach numbers the blade maximum mean lift coefficient for the NACA 64_1A012 section was about 0.08 less than was obtained with a blade having an NACA 0009 tip airfoil section and 0.21 less than was obtained with a blade having NACA 0012 sections.

2. The power increase from $M_t = 0.29$ to $M_t = 0.47$ for the NACA 64_1A012 blades at a value of $\bar{c}_l$ of 0.85 was about 35 percent compared with the 12- and 21-percent increases measured for NACA 0012 and NACA 0009 blades, respectively.

3. At $M_t = 0.69$ the rotor-blade mean lift coefficient for drag rise for the NACA 64_1A012 blade was 0.45 compared with values of 0.45 and 0.41 for the NACA 0012 and NACA 0009 airfoil blades, respectively.

4. The effective mean lift-curve slope required for an analytical prediction of the rotor thrust varied from an average of 5.8 at $M_t = 0.29$ to a value of 6.6 at $M_t = 0.74$.

5. The blade pitching-moment coefficients were small and relatively unaffected by changes in thrust coefficient and Mach number. In the instances in which stall was reached the moment break in the blade pitching-moment curves was in a stable direction.

6. The NACA 64_1A012 blades showed some tip relief as regards drag divergence at the higher Mach numbers in comparison with two-dimensional data. At the lower Mach numbers more data were needed to define accurately the exact point for drag divergence.

7. The efficiency of the rotor, expressed as figure of merit, decreased with an increase in tip Mach number. At $M_t = 0.29$, the maximum figure of merit was about 0.74. Similar measurements made on rotors having NACA 0009 and NACA 0012 airfoil sections showed values of 0.75.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., October 17, 1958.

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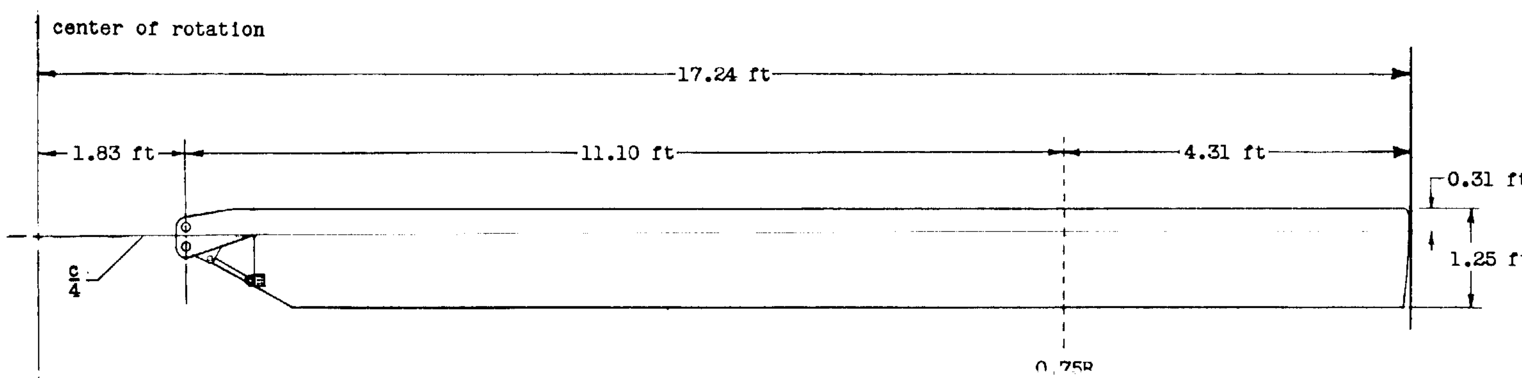


Figure 1.- Sketch of rotor blade having an NACA 64_1A012 section. $\theta_1 = -8^{\circ}$; $\sigma = 0.046$.

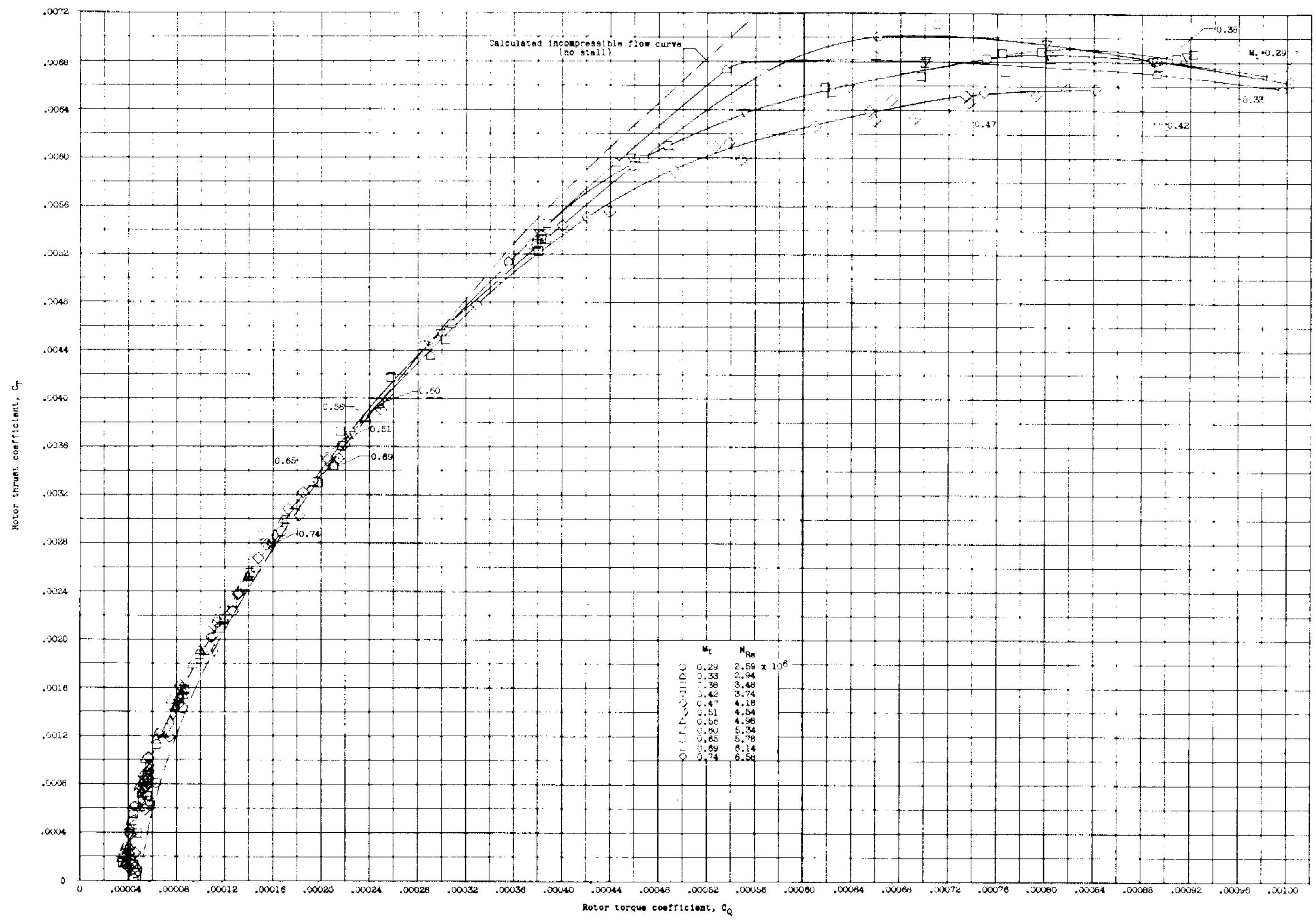


Figure 2.- Hovering performance of rotor blades having constant-chord NACA 64_1A012 sections. Calculated curve based on $c_{d,0} = 0.0087 - 0.0216\alpha_r + 0.400\alpha_r^2$ and $c_l = a\alpha_r$; $\sigma = 0.046$.

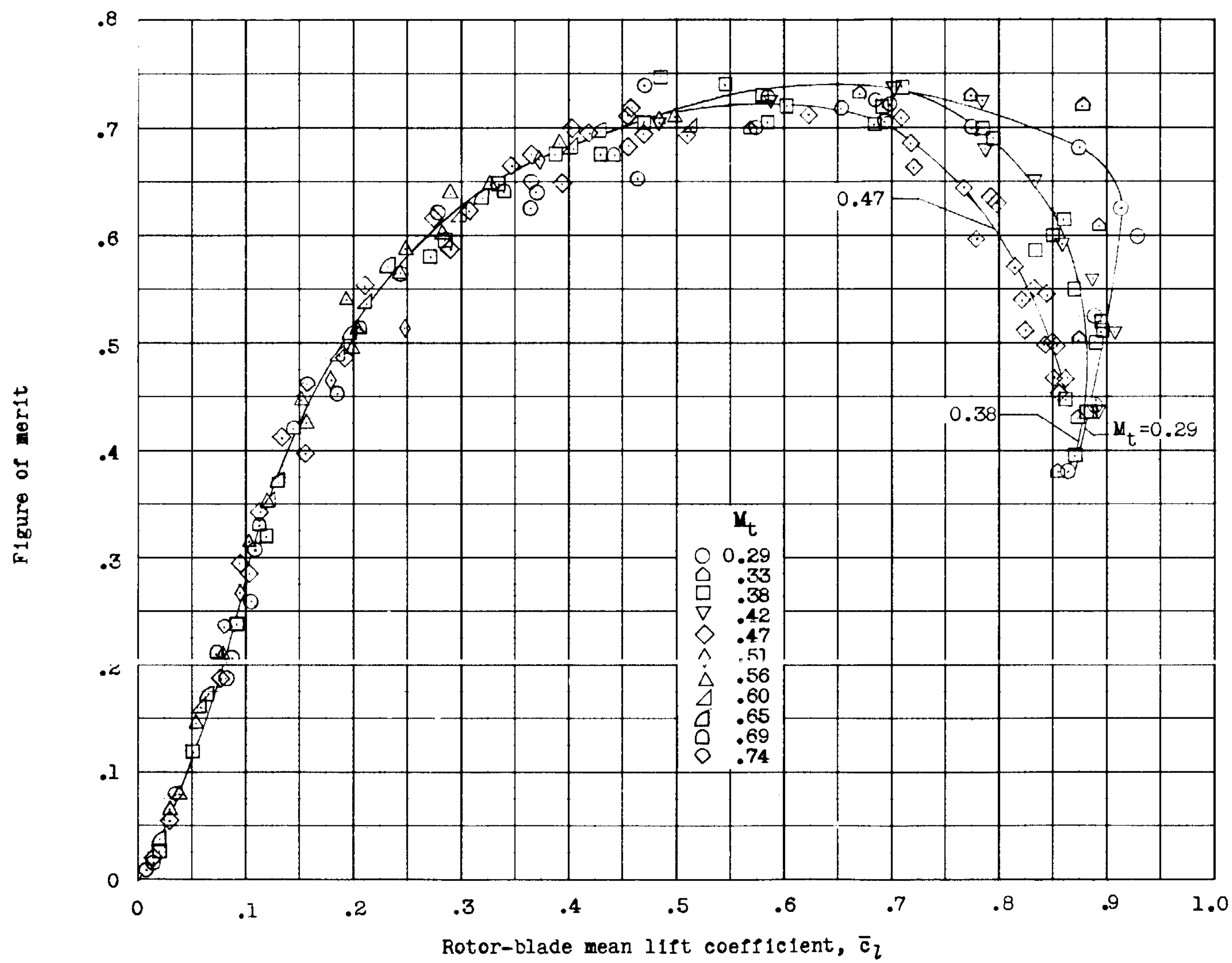


Figure 3.- Effect of tip Mach number on rotor figure of merit.

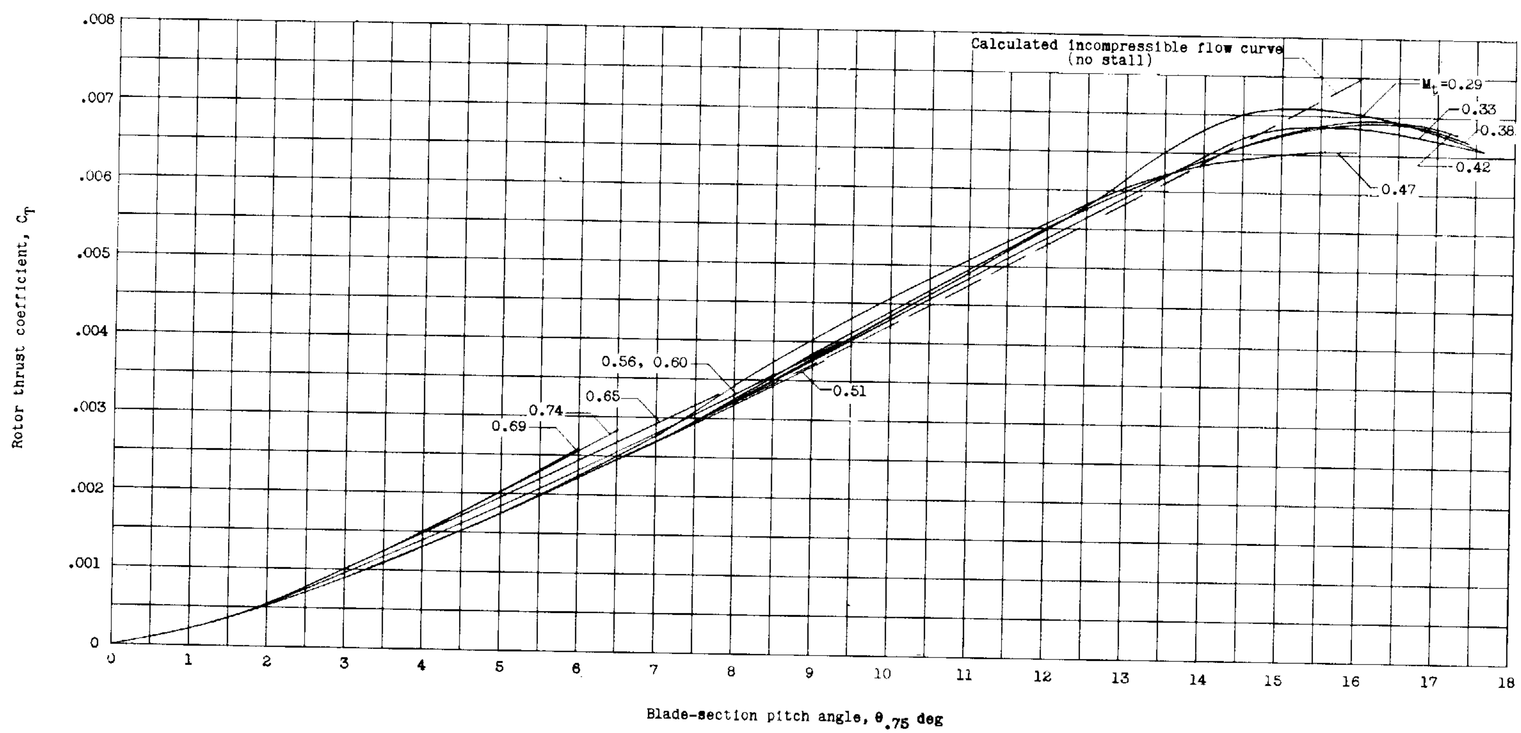


Figure 4.- Effect of tip Mach number on rotor thrust coefficient.

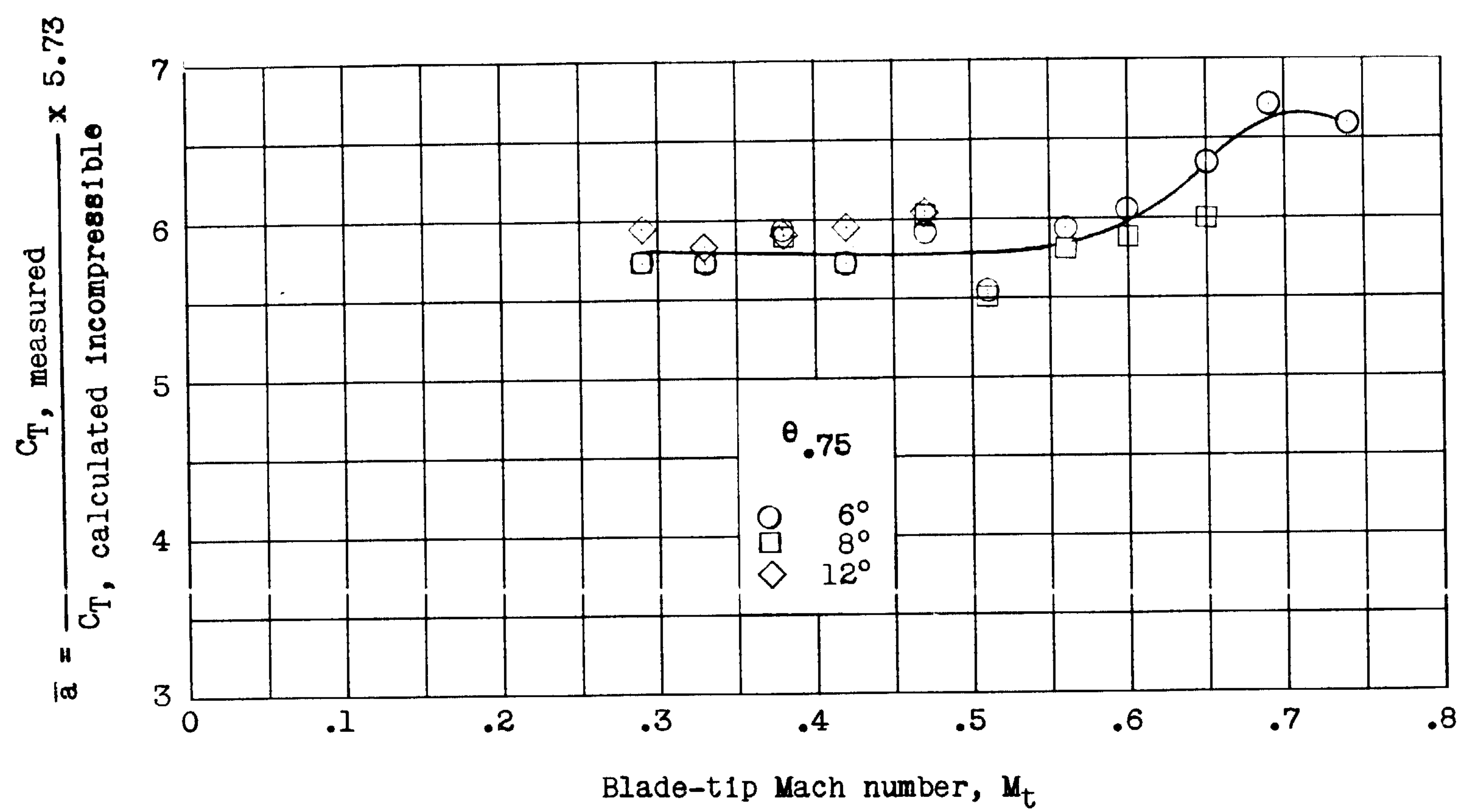


Figure 5.- Airfoil-section lift-curve slope required for predicting rotor thrust at various Mach numbers.

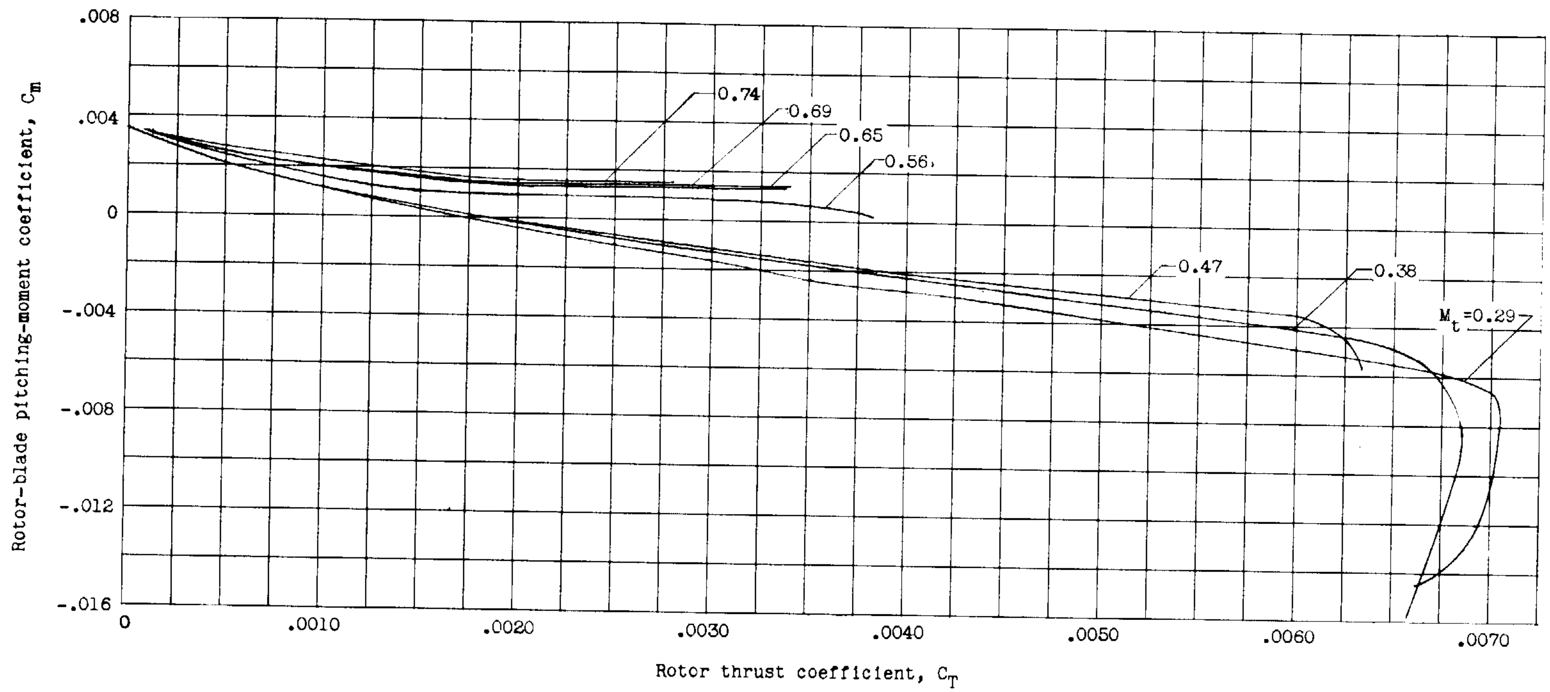
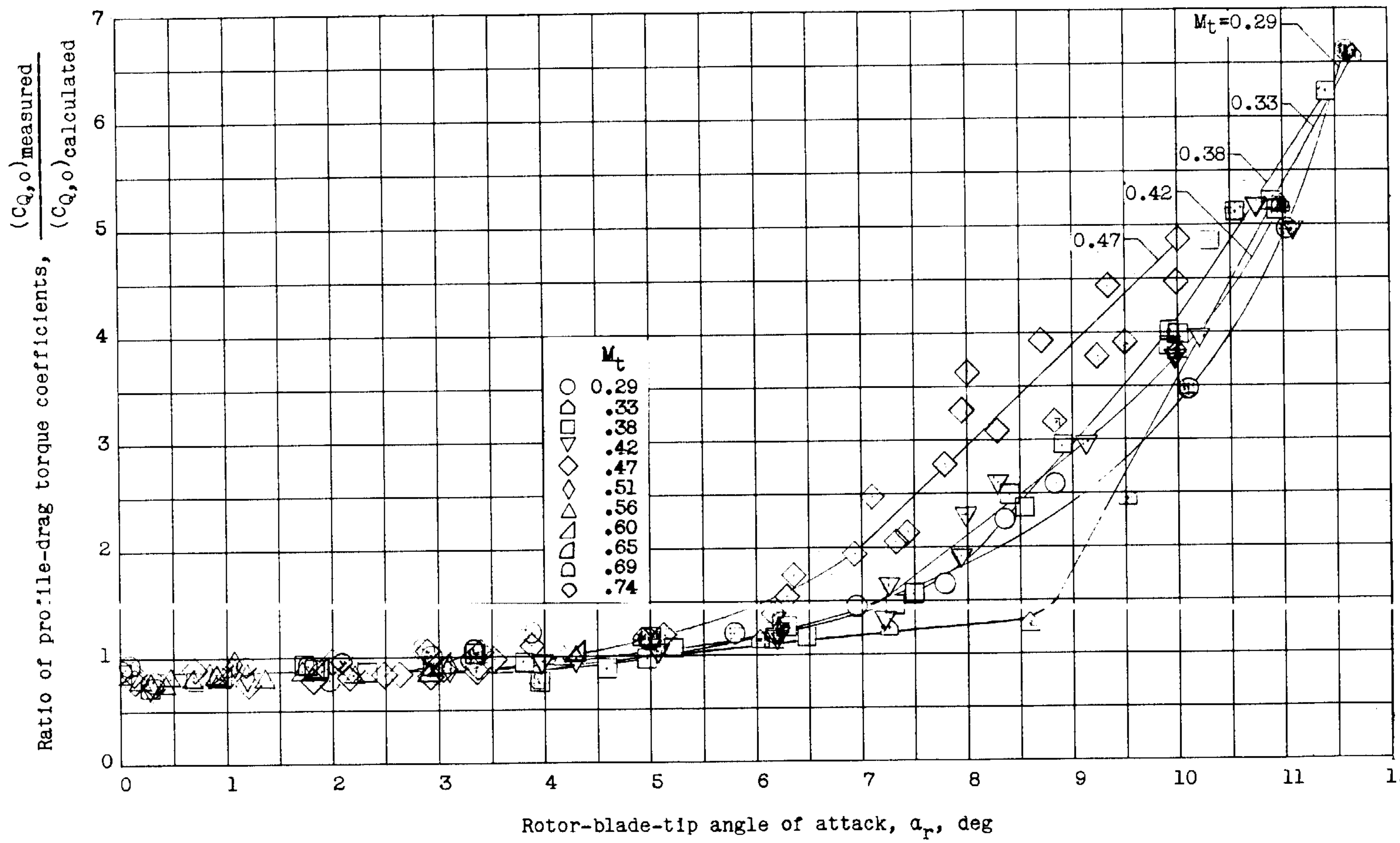
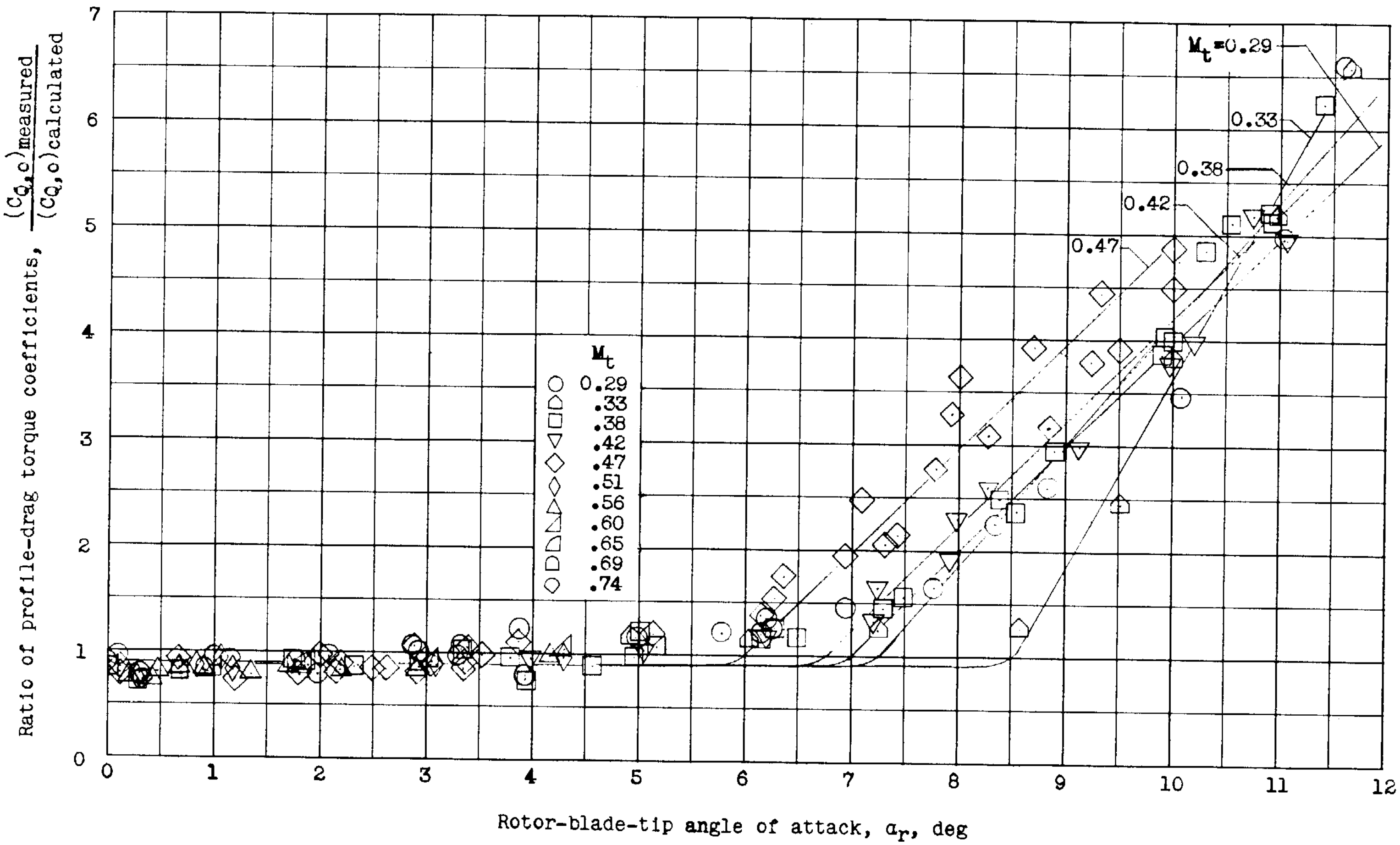


Figure 6.- Effect of tip Mach number on the pitching moments of rotor blades having NACA 64_1A012 airfoil sections.



(a) Faired through data points.

Figure 7.- Effect of tip angle of attack and Mach number on profile-drag torque ratio.



(b) Straight-line fairings.

Figure 7.- Concluded.

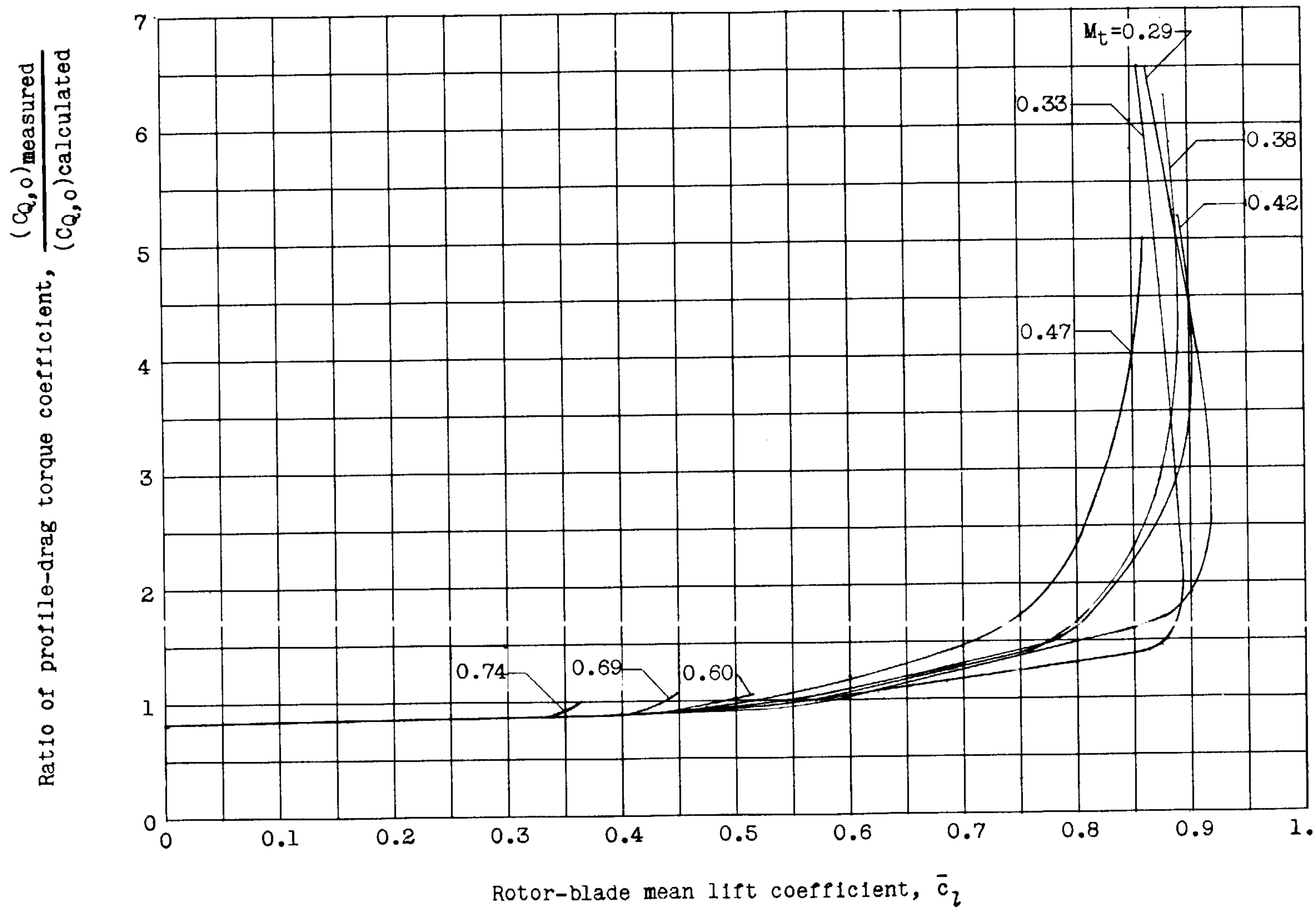


Figure 8.- Effect of rotor-blade mean lift coefficient and Mach number on profile-drag torque ratio.

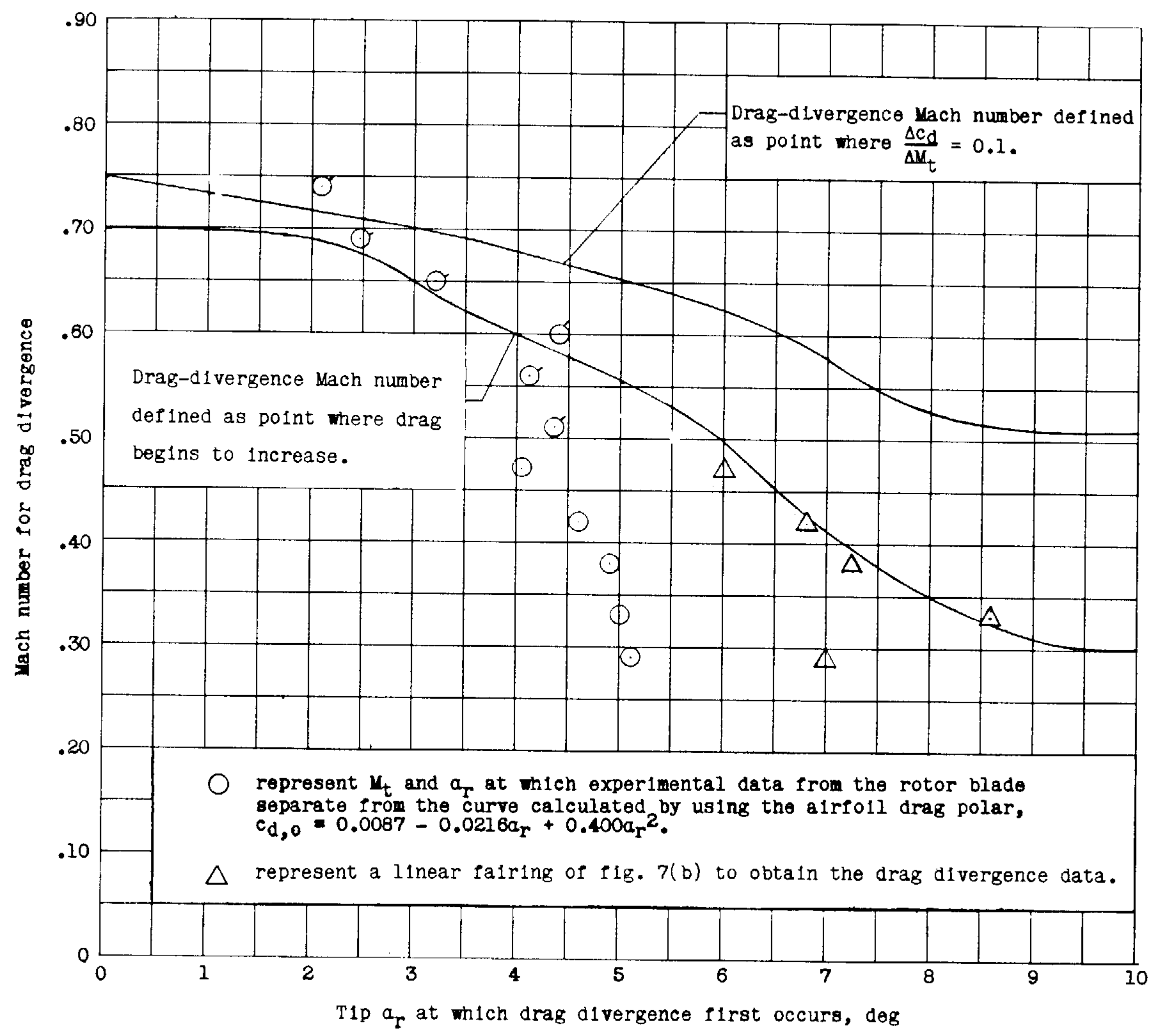


Figure 9.- Comparison of two-dimensional-airfoil drag-divergence data with the rotor experimental data. Solid lines represent NACA 64_1-012 airfoil-section two-dimensional data. Flagged values denote maximum values since drag-divergence data were incomplete.

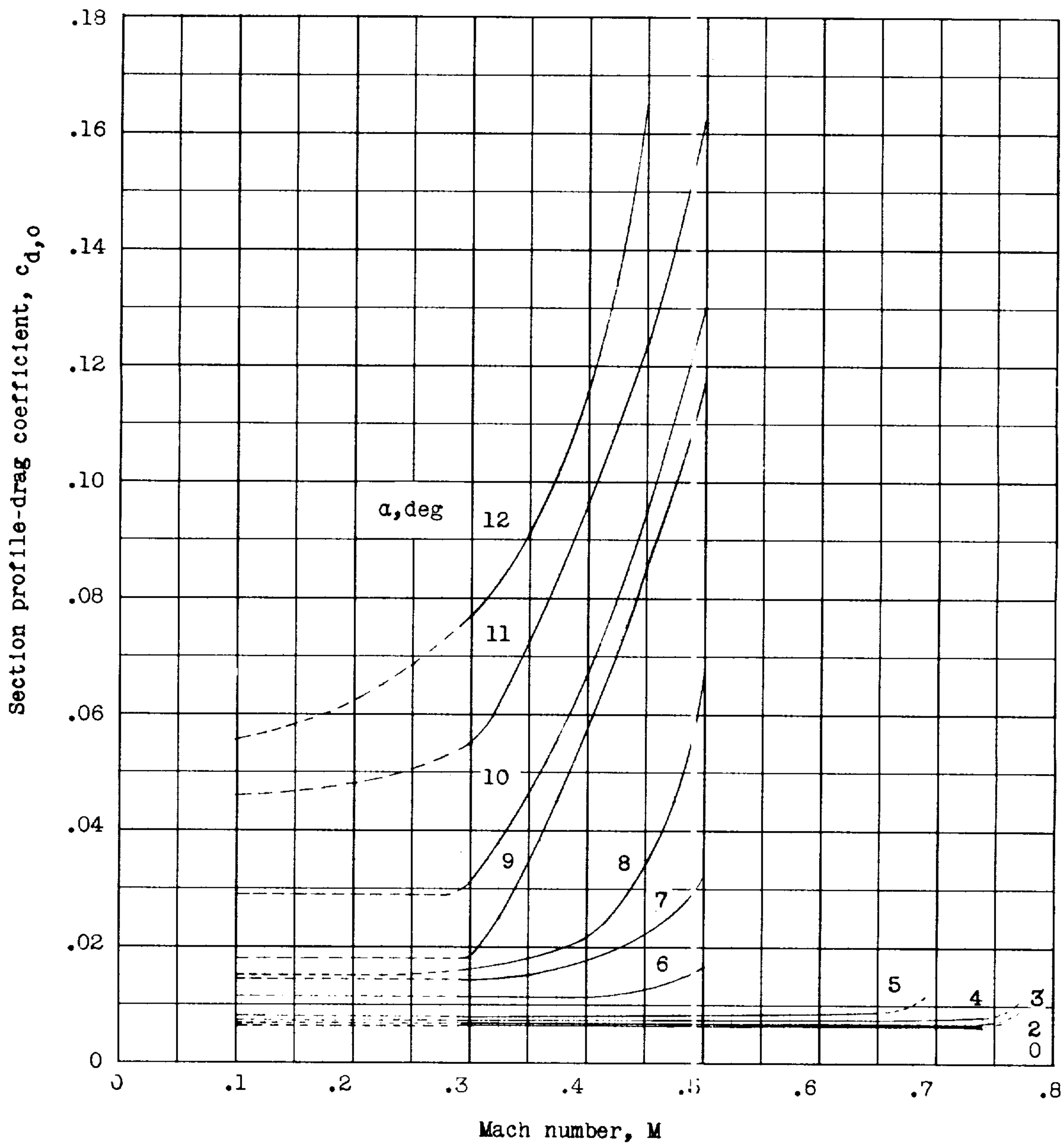


Figure 10.- Synthesized section profile-drag coefficient plotted against Mach number for the NACA 64_1A012 airfoil.

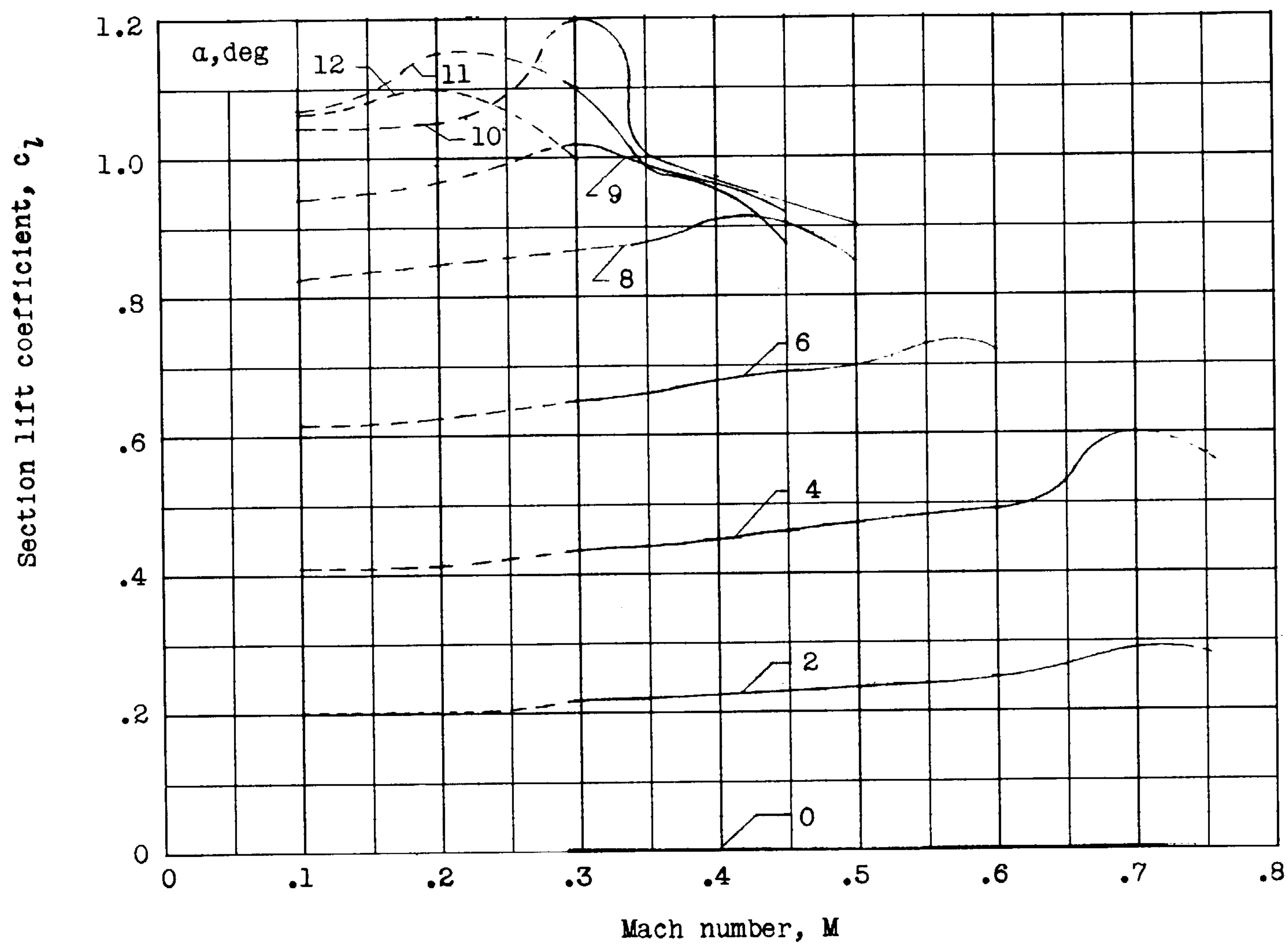


Figure 11.- Synthesized section lift coefficient plotted against Mach number for the NACA 64_1A012 airfoil.